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Goddard Space Flight Center
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(301) 286-5810 or
galcorn@gsfc.nasa.gov

Jet Propulsion Laboratory
Merle McKenzie
(818) 354-2577 or
merle.mckenzie@jpl.nasa.gov

Johnson Space Center
Hank Davis
(281) 483-0474 or
hanky.l.davis1@jsc.nasa.gov

John F. Kennedy Space Center
Jim Alberti
(321) 867-6224 or
Jim.Alberti-1@ksc.nasa.gov

Langley Research Center
Sam Morello
(757) 834-8005 or
s.a.morello@larc.nasa.gov

Glenn Research Center
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cto@grc.nasa.gov

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Sally Little
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(Code RW)
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rnorwood@mail.hq.nasa.gov

John Markins
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Terry Hertz
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(Code AS)
(202) 358-4636 or
thertz@mail.hq.nasa.gov

Glen Muucklow
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(Code SM)
(202) 358-2235 or
gmucklow@mail.hq.nasa.gov

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rcrouch@hq.nasa.gov

Granville Paules
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(Code Y)
(202) 358-0706 or
gpaules@mtpe.hq.nasa.gov

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Electronic Components and Circuits

Hardware, Techniques, and Processes

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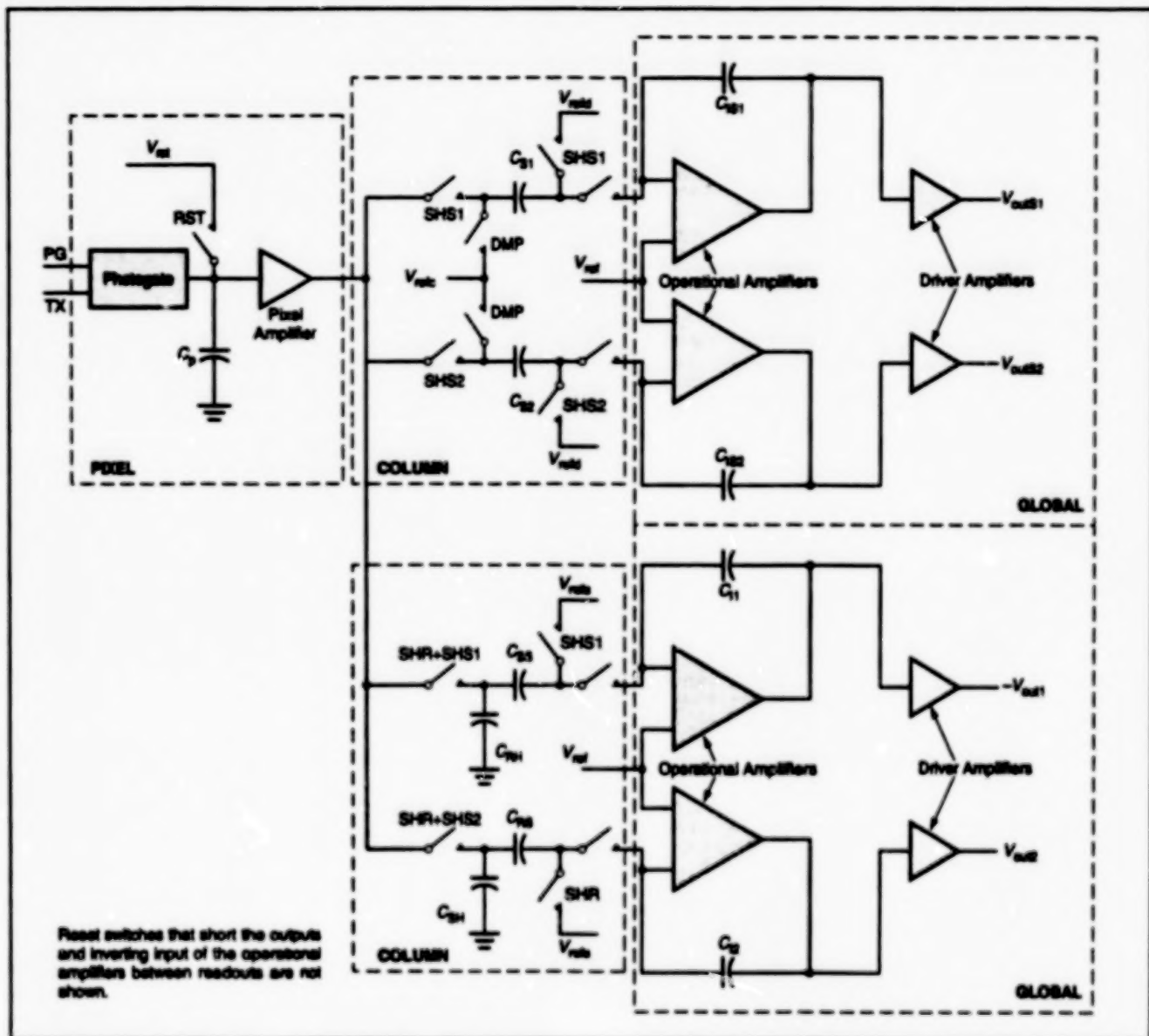
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Leakage-Compensated, Frame-Differencing APS Imager

This imager would also provide frame summing and suppression of fixed pattern noise.

NASA's Jet Propulsion Laboratory,
Pasadena, California



This Advanced APS Imaging Circuit would subtract or add (depending on applied timing signals) the pixel values of successive frames, using variable gain to compensate for leakage and a differential readout technique to suppress fixed pattern noise.

A proposed complementary metal oxide/semiconductor (CMOS) integrated-circuit imaging device of the active-pixel sensor (APS) type is capable of simultaneously generating the pixel-by-pixel sum and difference of two successive image frames at high speed for real-time operation, while compensating for leakage and suppressing fixed pattern noise (FPN). Frame differencing (and, to some extent, summing) is used in a variety of image-processing applications, including surveillance, range mapping, detection of motion, discrimination against background, compres-

sion of image data, and for solar-Doppler magnetographs.

Heretofore, it has been common practice to compute frame differences in software after acquiring image data, but such computation tends to be too slow for real-time operation and to contribute unfavorably to the complexity and power demand of an image-data-processing system. In an effort to overcome these disadvantages of frame differencing in software, APS circuits that incorporate capacitive memory elements and associated frame-differencing circuitry within pixels have been demon-

strated. Unfortunately, these circuits have been susceptible to unwanted coupling of present-frame pixel signals into pixel memory elements and consequent corruption of the stored previous-frame pixel values. Often, true frame differences are smaller than amounts of leakage, so that the very purpose of frame differencing is defeated. The problem of correcting frame-difference errors is compounded by a need to avoid contributing to FPN through inaccurate subtraction of pixel offsets. Regarding on-chip summing of successive frames: heretofore, there has been no circuitry

capable of performing this function.

The proposed imager would include pixel circuitry like that of prior CMOS APS imagers. It would differ from the prior imagers by incorporating redesigned column and global signal-processing circuits that would contain switched-capacitor gain stages (see figure). These redesigned circuits would (1) compute frame signals differentially to eliminate FPN; (2) provide different gains for present and preceding frame signals after FPN has been eliminated, in order to compensate for leakage; and (3) sum successive frames by use of modified gain-stage timing.

During exposure of the present frame, charge from the present frame leaks (by optical coupling or diffusion) into the in-pixel storage capacitor, C_p , corrupting the signal stored during the preceding frame. The effect of the leakage is equivalent to that of multiplying the present- and previous-frame signals by different voltage gains prior to the analog computation of the difference between them. Hence, the effect of leakage could be compensated by use of modified gains; in particular, if δ is the fraction of signal charge from the present frame that leaks into C_p , then one could compensate for the leakage by making the gain for the present frame $1 + \delta$ times that for the preceding frame.

In the proposed circuit, the outputs from the pixels in a given row would be sampled simultaneously at the bottoms of the corresponding columns in column sample-and-hold capacitors (C_{S1} and C_{S2}). These

capacitors would then be successively switched into the global switched-capacitor gain stage, which would include operational amplifiers, feedback capacitors (C_{S1} and C_{S2}), and transistor switches. The gain in each branch would be governed by the ratio between its capacitances. These ratios (C_{S1}/C_{S1} and C_{S2}/C_{S2} , respectively) would be chosen to obtain the different gains needed to compensate for leakage. The gains could be varied by changing capacitor sizes, by digital switching for parallel connection or disconnection of capacitors in increments of $0.01 \times$ a base capacitance.

In order to suppress FPN, it is necessary to effect pixel-to-pixel offset correction and suppression of flicker noise, and this necessitates equal gains. In the absence of a further correction, the use of different gains to compensate for leakage would contribute to FPN. In the proposed circuit, this correction would be effected by reading out each frame pixel value differentially with respect to an externally generated reference potential (V_{ref}), and storing the differential value in the charge domain on capacitors. Thus, offset would be corrected for each frame pixel value independently. The offset-corrected charge would then be appropriately amplified by the global switched-capacitor gain stage.

Generation of the sum of pixel values from two successive frames would involve sampling in different ways during the two frames. The signal from the preceding frame, already stored in C_p , would be captured by sampling that signal first, followed

by the reset. Inasmuch as the same reset level would be used for computation of the pixel value of the present frame, sampling of the current frame would begin with sampling of the reset voltage first, followed by sampling of the signal voltage. As a result, signals of opposite polarities would be generated in the two branches. Thus, when the difference between global differential outputs is computed, the result would be the sum of successive frame pixel values instead of the difference between them. Additional capacitors (C_{RH} and C_{SH}) would be needed in every column in order to store all four samples for a given pixel while individual columns were scanned out. Measured results indicate residual error of <1 percent, which is constant across the entire illumination range.

This work was done by Bedabrata Pain, Guang Tang, Monica Ortiz, and Suresh Seshadri of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to Technology Reporting Office

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(818) 354-2240

Refer to NPO-21049, volume and number of this NASA Tech Briefs issue, and the page number.

Magnetic Microimagers Based on Giant Magnetoresistance

Uses could include mineralogical exploration, detection of cracks, and reading magnetic cards.

Integrated-circuit imaging devices of a proposed type would contain planar arrays of microscopic sensors that would exploit giant magnetoresistance (GMR). Each GMR sensor in such a device would define one pixel in an image with a pixel pitch of the order of tens of microns. With the difference that the GMR sensors would respond to local magnetic fields instead of to locally incident light, they would perform essentially the same role as that played by photodetectors in familiar optoelectronic imaging devices. Indeed, the arrays of GMR sensors could be deposited on readout integrated circuits similar or identical to those on which, heretofore, visible and infrared photodetectors have been deposited. The proposed devices could be used, for example, as conventional

magnetometers and gradiometers, magnetic microscopes for examining small ferromagnetic particles or cracks in ferromagnetic materials, imagers for mineralogical exploration, and readers of magnetic inks and magnetic cards.

A typical GMR sensor according to the proposal (see Figure 1) would comprise several layers of magnetic materials separated by layers of nonmagnetic materials, all supported by a silicon substrate. With the exception of the substrate, the thicknesses of the layers would be of the order of tens of nanometers or less. The layers could be grown on the substrate by vacuum deposition, sputtering, or even electroplating. The growth and other fabrication steps would involve delicate nanotechnological techniques.

NASA's Jet Propulsion Laboratory,
Pasadena, California

The antiferromagnetic FeMn layer would serve to pin the orientation of the magnetization of the Co layer. The Co layer would be regarded as magnetically hard in that the applied magnetic field that one seeks to sense would not be strong enough to change the direction of magnetization of the Co layer. The NiFe layer, designated as the sensing layer, would be regarded as magnetically soft in that its coercivity would be less than that of the pinned (Co) layer and its direction of magnetization could be affected by the applied magnetic field that one seeks to sense.

GMR is a large change in electrical resistivity in response to a magnetic field applied along an axis of sensitivity that would lie in a plane parallel to the layer planes and that would be determined by

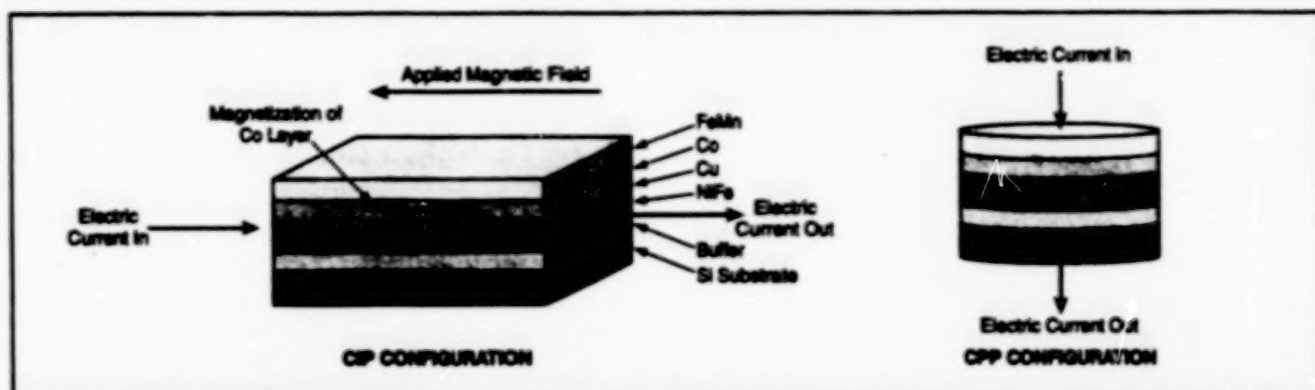


Figure 1. A Typical GMR Sensor would be constructed in either the current-in-plane (CIP) or current-perpendicular-to-plane (CPP) configuration. The electrical resistance of the device would vary with the applied magnetic field.

the direction of magnetization in the pinned layer. GMR is the macroscopic electrical manifestation of a phenomenon that is known as spin-valve action and that involves differential scattering, by the magnetic fields of the various layers, of electrons with different spin polarizations. In order to obtain GMR in the proposed device, the separated magnetic layers would have to be antiferromagnetically coupled. Inasmuch as the coupling between two magnetic layers oscillates from ferromagnetic to antiferromagnetic as the thickness of the intervening nonmagnetic layer is varied, it would be necessary to tailor the thicknesses of the nonmagnetic layers precisely in order to obtain the antiferromagnetic coupling needed to realize a highly sensitive GMR sensor.

Figure 2 shows the geometric relationship between an applied magnetic field, B , and the components of the magnetic field parallel and perpendicular to the axis of sensitivity of a GMR sensor, which could be one of many such sensors arrayed in the x - y plane. The sensor would respond only to the component B_y because the axis of sensitivity as depicted here is oriented parallel to the y axis. In order to sense the component B_x , it would be necessary to rotate the sensor 90° about the z axis to make the

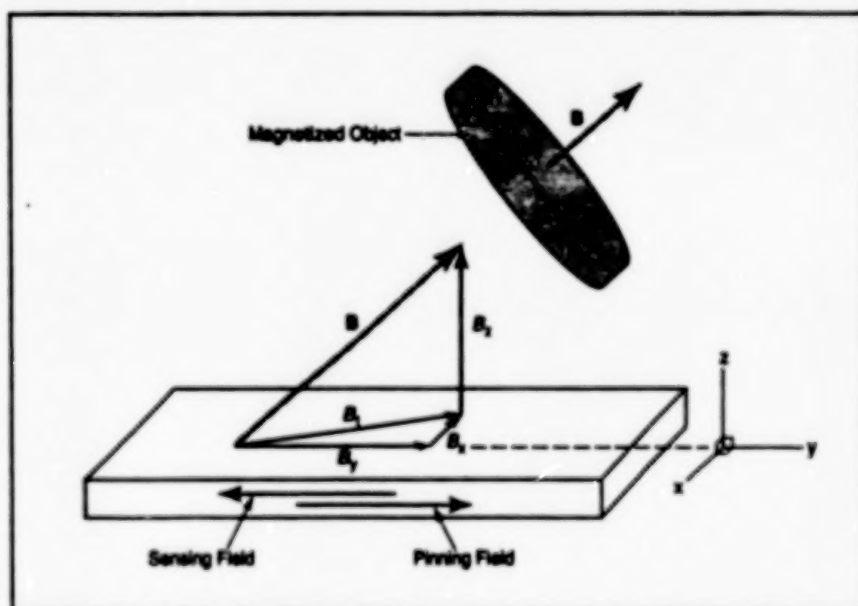


Figure 2. The Orientation of a Magnetic Field relative to the axis of sensitivity of a GMR sensor would affect the sensor response.

axis of sensitivity L_s parallel to the x axis. Similarly, in order to sense B_z , it would be necessary to rotate the sensor 90° about the x axis to make the axis of sensitivity L_s parallel to the z axis. Alternatively, it should be possible to construct an imaging device containing a two- or three-dimensional array of GMR sensors with orthogonal axes

of sensitivity, so that it would be possible to sense B_x and B_y or even B_x , B_y and B_z simultaneously.

This work was done by Sir B. Reel of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20925

Using Ferromagnetism and Giant Magnetoresistance To Sense IR

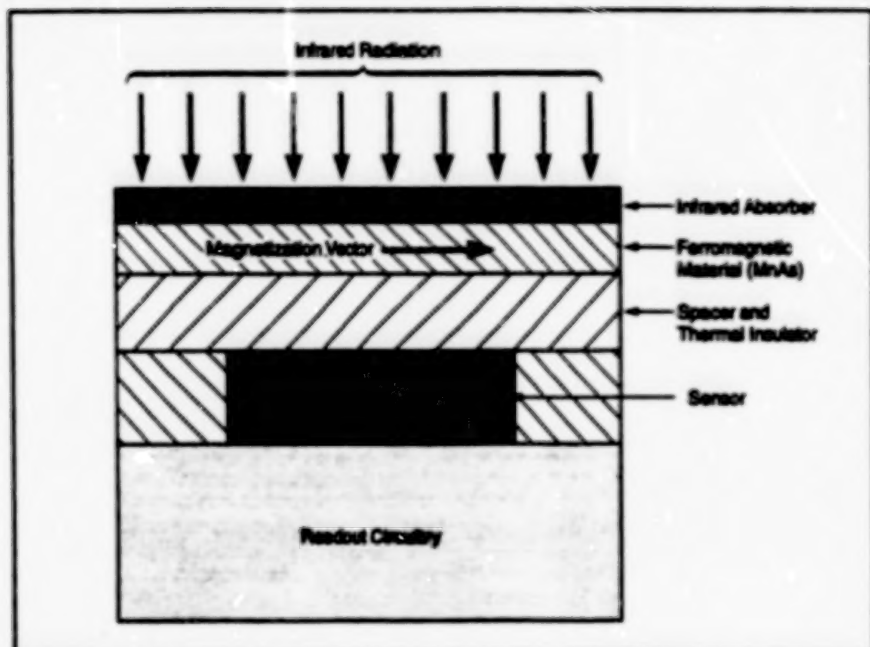
Proposed sensors and imaging devices could operate at room temperature.

Infrared (IR) sensors of a proposed type, and integrated-circuit imaging devices containing planar arrays of such sensors, would be based on a combination of (1) temperature-dependent ferromagnetism and (2) the use of giant magnetoresistance (GMR) to detect changes in ferromagnetism. Unlike many infrared sensors, the proposed sensors would not have to be

cooled to very low temperatures; indeed, they could be designed for optimum performance at room temperature.

A sensor according to the proposal (see figure) would include a layer of ferromagnetic material coated with an infrared-absorbing material. The ferromagnetic material would be heated by incident infrared radiation. The chosen

ferromagnetic material would be one with a Curie temperature (T_c) somewhat above the intended operating temperature; for example, MnAs ($T_c = 318$ K) would probably be suitable for room temperature (≈ 293 K). The reason for this choice is that the magnetization of a ferromagnetic material decreases sharply with increasing temperature as the tem-



Infrared Radiation would be absorbed, causing warming of the ferromagnetic layer to near its Curie temperature and thus a decrease in magnetization. The GMR portion of the sensor would sense the change in magnetization.

perature approaches T_c , so that the magnetic field produced by such a material can serve as a sensitive indicator of temperature in the range just below T_c . Hence, one would expect the magnetic field of the ferromagnetic material to

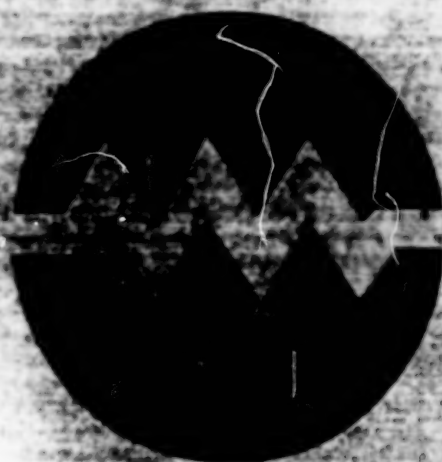
decrease when the material was heated by incident infrared radiation.

A GMR sensor is a multilayer device (for example, see the preceding article) that exhibits a change in electrical resistance when exposed to a change in a magnetic

field. Some GMR sensors are capable of detecting changes in magnetic-flux density as small as 1 milligauss (10^{-7} Tesla). The GMR portion of the proposed sensor would sense the temperature-dependent change in the magnetic field of the ferromagnetic layer. The ferromagnetic layer would be separated from the GMR layers by a nonmagnetic layer with a thickness chosen to provide both magnetic coupling and sufficient thermal insulation to enable the temperature of the ferromagnetic layer to rise appreciably upon exposure to infrared radiation.

One of the advantages of both ferromagnetic materials and GMR sensors is that they can be engineered to operate at a chosen temperature with acceptably high sensitivity. Furthermore the layers of a GMR sensor are easily grown by sputter deposition and molecular-beam epitaxy. According to the proposal, the GMR layers would be deposited directly on a readout integrated circuit, followed by deposition of the nonmagnetic, ferromagnetic, and infrared-absorbing layers.

This work was done by Sir B. Reel of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1], NPO-20929



Electronic Systems

Hardware, Techniques, and Processes

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Improved Encryption-Mode GPS Receiver

An auxiliary antenna is used to improve the estimate of the GPS A-code.

NASA's Jet Propulsion Laboratory,
Pasadena, California

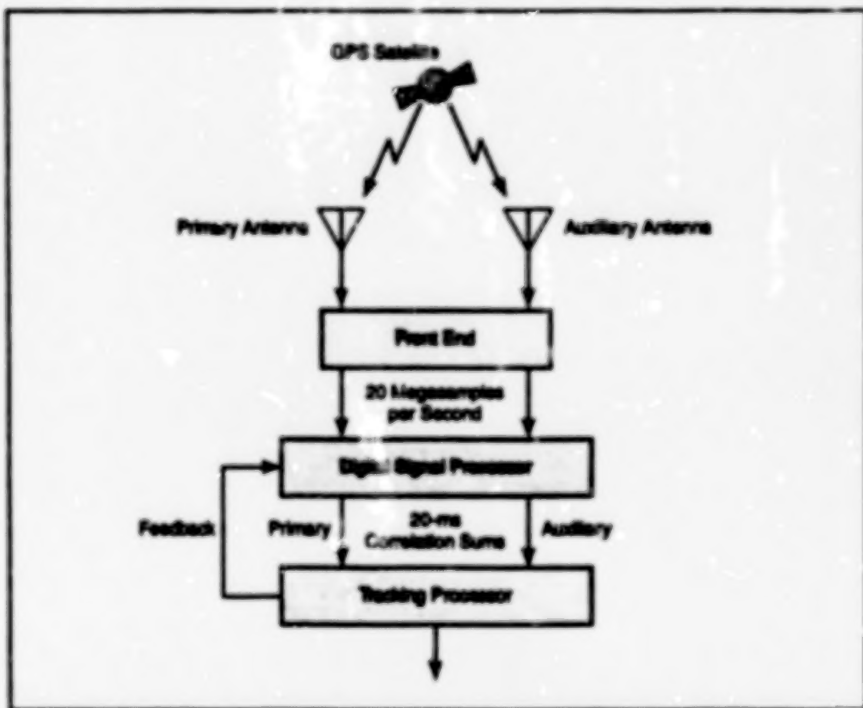
An improved Global Positioning System (GPS) receiver, which processes an encrypted P-code signal without knowledge of the encryption code (denoted here as A-codeless mode), includes an auxiliary antenna and associated additional signal-processing circuitry. The improved design of this receiver makes it possible to achieve signal-to-noise ratios (SNRs) greater than that of prior A-codeless-mode GPS receivers, especially when GPS satellites appear at low elevation angles.

The GPS P-code signals are sometimes modulated by a secret binary code, denoted here as the "A-code," for use in sensitive military and other government applications to prevent jamming signals from being accepted as GPS satellite signals. Full precision in timing and positioning measurements can be obtained by correcting for the A-code, if it is known. In the absence of knowledge of the A-code, one can still obtain useful precision by estimating the A-code.

The need for the improved design arises because, in the A-codeless mode, performance deteriorates significantly when antenna gain is low. For example, the choke-ring antennas customarily used in some GPS receivers are designed to have very low gains at low elevation angles in order to reduce multipath errors. These low gains result in low SNRs, particularly in the A-codeless mode.

The basis of the improved design is the following: The A-codeless-mode SNR of a GPS receiver can be greatly increased at low elevation angle or low gain, without compromising the multipath rejection of choke-ring antenna, by use of an auxiliary antenna with a gain pattern that complements that of the choke-ring antenna; that is, with a high gain at low elevation angles. The signal received by the auxiliary antenna is used solely to improve the estimate of the A-code in the signals received by the primary antenna. The signals received by the choke-ring or other primary antenna are subjected to the customary GPS processing to obtain delays and phases, but now the estimates of the delays and phases are improved by use of the improved estimate of the A-code.

The auxiliary antenna is either placed near the primary antenna or else is part of



The signal received by the Auxiliary Antenna is processed to improve the estimate of the GPS A-code in the signal received by the primary antenna. The net result is an increase in the effective SNR.

the primary antenna structure. In the front end of the receiver (see figure), the radio-frequency signal collected by the auxiliary antenna is down-converted to baseband and converted to digital samples in the same fashion as that of the signal from the primary antenna. The resulting quadrature baseband samples are fed to a digital signal processor (DSP), where they are processed in a separate channel with the same operations as those performed on the signal from the primary antenna.

The DSP operates in a feedback relationship with a tracking processor, wherein the main and auxiliary signals are tracked in separate channels by use of separate tracking loops for delay and phase in each channel. As is typical in a GPS receiver when in lock, the in-phase (I) component in each antenna channel contains almost all of the counterrotated signal strength, while the quadrature (Q) component is small and reflects the phase-tracking error.

When the stand-alone SNR of the primary channel is approximately equal to or less than the stand-alone SNR of the auxiliary channel (as when the GPS satellites

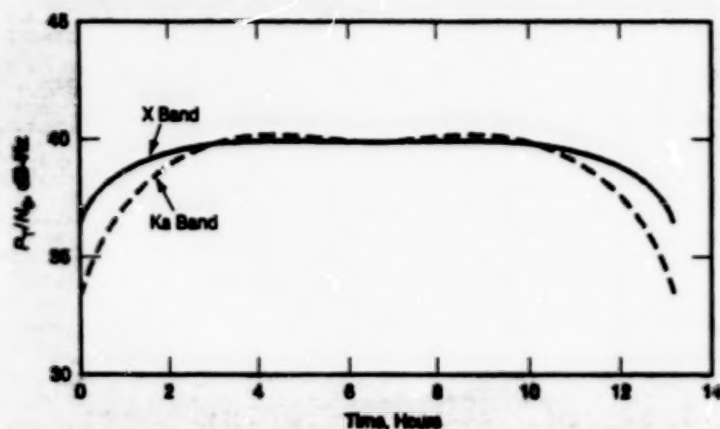
appear at low elevation angles), the effective SNR for phase and delay in the primary channel can be increased by making use of the prompt I component in the auxiliary channel to improve multiplicative corrections in the primary channel that tend to remove the A-code signal from I and Q components. Logic circuitry in the tracking processor determines when and how to use the prompt I component in the auxiliary channel for this purpose. A description of how this is done would greatly exceed the space available for this article. Suffice it to say that the effective SNR for phase and delay can be increased by an amount that typically lies between 0 dB (for an auxiliary signal weaker than the primary signal) and approximately 14 dB (for an auxiliary signal stronger than the primary signal).

This work was done by J. Brooks Thomas, Thomas Meenan, and Lawrence Young of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20784

Variable Telemetry Playback Rate for Increased Data Return

The rate is adjusted nearly continuously according to a predicted signal-to-noise ratio.

NASA's Jet Propulsion Laboratory,
Pasadena, California



This example of P_T/N_0 as a function of time was computed for a representative case of a distant spacecraft at 25° declination, tracked by a Deep Space Network receiver at Goldstone, California.

In a scheme to increase the overall data return from a phase-modulation, suppressed-carrier telemetry transmitter, the telemetry playback symbol rate is adjusted essentially continuously. More precisely, the playback symbol rate is adjusted frequently (as often as once per symbol period) in small increments. The adjustment of the rate is made in accordance with the principle that the supportable data rate at any given instant is a function of the instantaneous total signal-power-to-noise spectral-density ratio (P_T/N_0) at the receiver. The scheme was devised for transmission of telemetric data from deep-space missions, but could also be applied to satellites in orbit around the Earth.

P_T/N_0 is a known function of the receiving-station gain-to-noise-temperature ratio (G/T), which, in turn, is a known function of the position of the transmitter relative to that

of the receiver. Thus, once the trajectory of the transmitter relative to the receiver position has been predicted, then G/T or P_T/N_0 as a function of time can be estimated (see figure); this estimate can be computed aboard the spacecraft or uploaded to the spacecraft prior to a portion of a trajectory (a tracking pass) and the corresponding interval of time during which the telemetry signal is expected to be received. Then during the tracking pass, the playback symbol rate at the transmitter is adjusted in accordance with the predicted G/T .

Traditionally, the telemetry symbol rate (equivalently, the telemetry data rate) for a deep-space mission is either fixed or is changed only a few times during a pass. A change in the data rate often entails a large, instantaneous jump, which can sometimes cause the ground receiving system to lose symbol lock. Upon losing lock, the receiver

begins to lose some or all of the incoming telemetry data and must go through a signal reacquisition process in order to regain lock. The time lost in reacquisition could be large enough to nullify any advantage gained by changing the data rate. Although there are ways to minimize the probability of losing receiver lock during data-rate changes, they are operationally complicated and often require very precise predictions of the times when the rate changes will take place.

In the present scheme, a precise prediction of the instantaneous data rate is not needed. [However, coarse data-rate predictions are needed for initial acquisition and for reacquisition after mode changes (not to be confused with rate changes).] In this scheme, the symbol clock in the transmitter has a continuous phase; in other words, even when the clock frequency changes abruptly, the clock phase remains continuous. Because of the continuity of phase and the smallness of the clock-frequency increments, the symbol-tracking loop in the receiver is subjected to only small transient phase errors that do not cause it to lose lock. Experiments and computational simulations for some typical cases have shown that a receiver can, indeed, track the small frequent rate changes and that the telemetry returns achievable by use of this scheme exceed, by 1 to 2 dB, those achievable by use of the best single-rate scheme.

This work was done by Miles K. Sue, Jeff B. Berner, Selahattin Kayeler, and Henry Hotz of Caltech; Peter Kinman of Case Western Reserve University; and Harry Tan of Q-Plus for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

NPO-21024

Low-Power, Sparse-Sampling GPS Receiver

Performance can approach that of a heavier, higher-power, full-fledged GPS receiver.

NASA's Jet Propulsion Laboratory,
Pasadena, California

The term "microGPS" denotes a Global Positioning System (GPS) receiver design concept that combines relatively simple, lightweight, low-power-consumption hardware with portable, efficient software. The power demand of a microGPS receiver can be made low because it is designed to sample sparsely; that is, to "awaken" from a "sleep" mode only occasionally to sample GPS signals during short intervals.

MicroGPS was conceived for navigational use aboard some small Earth-orbiting satellites for which full-fledged GPS receivers would be too complex, massive, and power hungry, and for which positioning errors as large as a few hundred meters would be acceptable as part of the price of low mass and low power consumption. The microGPS concept may also prove attractive for terrestrial applica-

tions that involve similar design tradeoffs.

The hardware of a prototype microGPS receiver aboard the Student Nitric Oxide Explorer (SNOE) spacecraft consists of a lightweight patch antenna and receiver circuits that include an inexpensive oscillator, a down-converter/sampler, and a memory chip. The receiver circuits consume a peak power of 875 mW during acquisition of samples of GPS signals and a power of 75

mW during standby (with the oscillator running, ready for commands). For the SNOE mission, GPS signal data are acquired during sampling periods 20 ms long, once every 15 minutes (about 6 times per orbit). The volume of data is about 450 kilobytes per day. The GPS samples are stored in the memory chip for subsequent processing.

In order to offer maximum flexibility in satellite design, the microGPS orbit-determination software is designed for execution either aboard the spacecraft or on the ground. In the latter case, the sparse GPS samples are telemetered to the ground and processed in post real time to compute spacecraft orbits that can be uploaded to the satellite and projected ahead for use in real time. Aboard the spacecraft, the software could be executed either in the flight computer of the spacecraft or in a special-purpose processor within the microGPS hardware unit (with slight increases in mass and power consumption).

The mass of the receiver, including the patch antenna, is only 595 g. The aspect of the receiver design that makes it possible to achieve such a low mass is a modified architecture in which all of the GPS-specific signal processing typically implemented in parallel on special-purpose hardware in other GPS receivers is, instead, implemented serially in software. Moreover, whereas the amount of computation to acquire signals in other GPS receivers is approximate-

ly proportional to N^2 (where N is the number of discrete time samples), the amount of computation is proportional to $\ln(N)$ in this receiver due to the use of frequency-domain processing.

The sequential time-tagged GPS signal samples are down-converted, filtered, and quantized to a single bit. The receiver samples the signal at a rate of about 20 MB/s but can be programmed to perform a sum-and-dump filtering and decimation function to reduce the data rate to about 2 MB/s. The sampled data are searched in Doppler shift (over a range of ± 45 kHz) and in delay (over 1 repeat cycle (1 ms) of the Coarse-Acquisition (C/A) code). The search for GPS signals and the extraction of observables (Doppler shifts and pseudoranges) is effected by use of a Fourier-transform-based technique of time-domain correlation.

There is an important distinction between the usual GPS pseudorange and the pseudorange in microGPS: Whereas the usual GPS pseudorange represents absolute, unambiguous range (plus transmitter and receiver clock offsets), the reliability of the pseudorange in microGPS is limited by an ambiguity of 1 ms (300 km); this is because the 20-ms sampling period is not long enough for either decoding the GPS navigation-data message (and thus GPS time is unavailable) or reliably determining the times of

the bit transitions of the message.

The range ambiguity is resolved by further processing in three steps. First, a crude (accurate to within 50 km) orbit is computed by use of the Doppler data from multiple GPS satellites. Next, a set of unambiguous range data is computed from a combination of this crude orbit and the GPS-satellite orbits, which are known to far better accuracy. Finally, the ambiguity is resolved by direct comparison of this unambiguous set of computed range data with the ambiguous microGPS pseudorange data.

This work was done by Stephen Lichten, Thomas Meehan, Jeffrey Srinivasan, Sen-Chong Wu, and Lawrence Young of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-20835, volume and number of this NASA Tech Briefs issue, and the page number.

Acquisition, Tracking, and Pointing in Optical Communication

A document in the form of lecture slides outlines a program of development of capabilities for acquisition of signals, tracking of signal sources, and pointing of transmitters and receivers in deep-space optical communications. Topics addressed on the first few slides include the benefits and challenges of optical communications and the historical and organizational background of continuing development efforts. Most of the remaining slides address selected technical aspects of acquisition, tracking and pointing (ATP) in various levels

of detail; these aspects include basic principles of operation, beam-pointing requirements, sources of tracking and pointing errors, alternative approaches to tracking and pointing, concepts for the design and operation of ATP systems, and key technological developments that are necessary for attaining required levels of ATP performance. The last slide summarizes the major technical challenges; these include the difficulty of pointing the necessarily narrow transmitted laser beams, the need to suppress spacecraft vibrations in

beam-pointing equipment, the need for bright beacons, and interference by scattered sunlight.

This work was done by Shinhak Lee, James W. Alexander, and Gerardo L. Ortiz of Caltech for NASA's Jet Propulsion Laboratory. To obtain a copy of the document, "Deep Space Acquisition, Tracking, Pointing (ATP) Technologies for Optical Communication," see TSP's [page 1]. NPO-20889



Physical Sciences

Hardware, Techniques, and Processes

- 19 RVSM Certification of Dryden DC-8 Airborne Laboratory
- 20 Measuring Contact Angles of a Sessile Drop and Imaging Convection Within It
- 21 Field-Reversed Magnetic Mirrors for Confinement of Plasmas
- 22 Updated Multidisciplinary Optical-System-Analysis Software

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RVSM Certification of Dryden DC-8 Airborne Laboratory

A required pressure-altitude accuracy of ± 160 ft (± 49 m) has been achieved.

Dryden Flight Research Center,
Edwards, California



Figure 1. The NASA Dryden Airborne Science Laboratory is contained in a DC-8 airplane (N817NA).

The NASA Dryden DC-8 Airborne Science Laboratory (see Figure 1) performs research around the globe, recently in support of the SAGE III Ozone Loss and Validation Experiment (SOLVE). This experiment operated in the North Atlantic airspace region, which is subject to reduced vertical separation minimum (RVSM) requirements (see Figure 2). These requirements allow aircraft traffic to be separated vertically by a minimum of 1,000 ft (304.8 m) at altitudes between 29,000 and 41,000 ft (between 8.84 and 12.50 km) above mean sea level, in contradistinction to the usual vertical separation of 2,000 ft (0.61 km). RVSM non-group aircraft compliance requires a pressure-altitude accuracy within ± 160 ft (± 49 m). RVSM allows greater traffic density while maintaining safe aircraft separation.

A commercial service for RVSM certification was considered, but involved significant modification of the aircraft, high cost, and an unacceptable effect on the schedule of airborne scientific research for which commitments had been made. Instead, it was decided to perform the RVSM certification internally, with insignificant modification of the aircraft, at minimal cost, and with little effect on the schedule. The objective of the certification effort was to achieve the required accuracy of ± 160 ft (± 49 m) through an airdata calibration of the DC-8 static-pressure system.

RVSM-quality airdata computers were installed in the DC-8 airplane, and the data were recorded by use of a data-acquisition and -distribution system (DADS) that is part of the standard laboratory equipment in the aircraft. These airdata computers have a worst-case avionics error of 85 feet (26 m) after 24 months. For the calibration flights, a

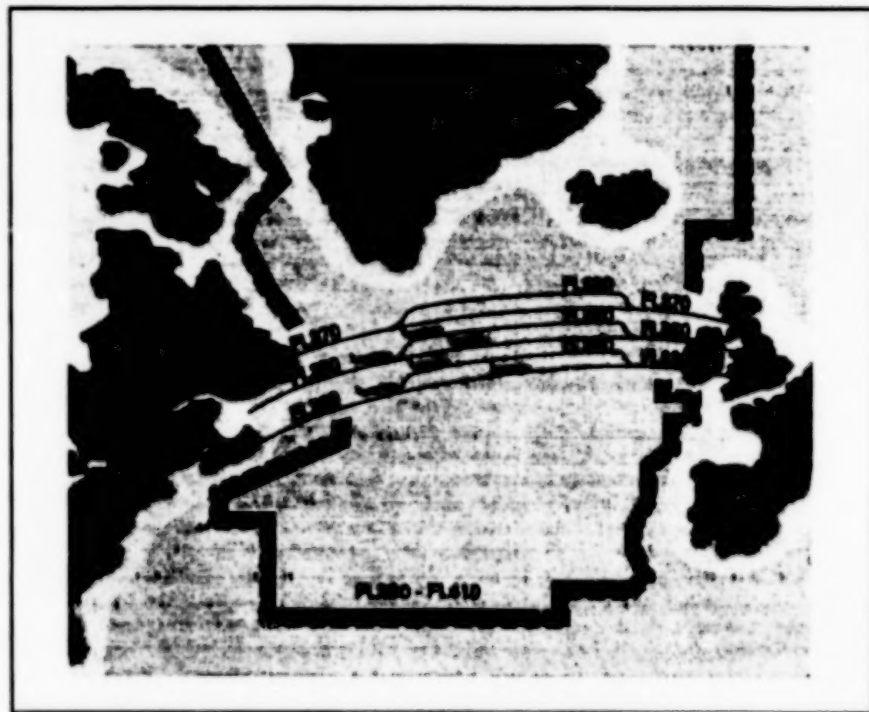


Figure 2. This Map Depicts the RVSM Airspace in the North Atlantic.

carrier-phase differential Global Positioning System (DGPS) receiver and antenna were employed. The DGPS gave geometric altitude of the aircraft to an accuracy better than 2 feet (0.6 m). A pressure calibration of the atmosphere on flight-test days was determined by data from a network of rawinsonde weather balloons, synoptic analysis, and surface observations.

By combining DGPS geometric altitude with the pressure calibration of the atmosphere, the true pressure altitude of the aircraft was determined. This was compared to the airdata computer measurement with no error corrections to determine the static source error correction (SSEC) required to

null the pressure-altitude errors. (The SSEC is a function of the mach number only.) The SSEC for both the pilot and copilot systems were then incorporated into the airdata computers and checked on a verification flight.

The DC-8 airplane was flown at an altitude of 500 ft (152 m) above Rogers Dry Lakebed near maximum speed (mach 0.48 to 0.54) in steady flight. These data gave the SSEC with minimal uncertainty of the atmospheric pressure calibration. The remaining majority of flight data were taken at altitudes from 29,000 to 41,000 ft (8.84 to 12.50 km) in stabilized flight between mach 0.51 and mach 0.86. The

near-ground data were used to adjust the high-altitude data for small temperature biases on the rawinsonde balloons. DGPS data taken during constant-air-speed turns were used to measure winds independent of the rawinsonde balloons. Autopilot operation was verified during stabilized flight to conform to an RVSM requirement of ± 65 ft (± 20 m).

One calibration flight was for the purpose of determining the SSEC required to null pressure-altitude errors with the aircraft in a clean configuration. The data obtained on this flight yielded residual

errors of ± 15 ft (± 4.6 m) for both the pilot and copilot static-pressure systems.

On a verification flight, the aircraft was instrumented with a variety of external scientific probes, including a large nacelle about 5 ft (1.5 m) from the static-pressure ports. This configuration of probes constituted a near worst-case configuration for possible SSEC shifts. The maximum residual error on this flight was 73 ft (22 m) and, when combined with the worst-case avionics error of 85 ft (26 m) and the DGPS error of 2 ft (0.6 m), resulted in a total error of 160 ft (49 m), just satisfying

the RVSM requirement. The errors would be considerably less if the airborne scientific probe near the static ports were removed or relocated. Autopilot operation was demonstrated to be within ± 30 ft (± 9 m). RVSM certification was granted on November 18, 1999.

This work was done by Edward A. Heering, Jr., Edward H. Teets, Jr., and David A. Webber of Dryden Flight Research Center.

DRC-00-11

Measuring Contact Angles of a Sessile Drop and Imaging Convection Within It

Ordinary and laser-shadowgraph images yield valuable information.

John H. Glenn Research Center,
Cleveland, Ohio

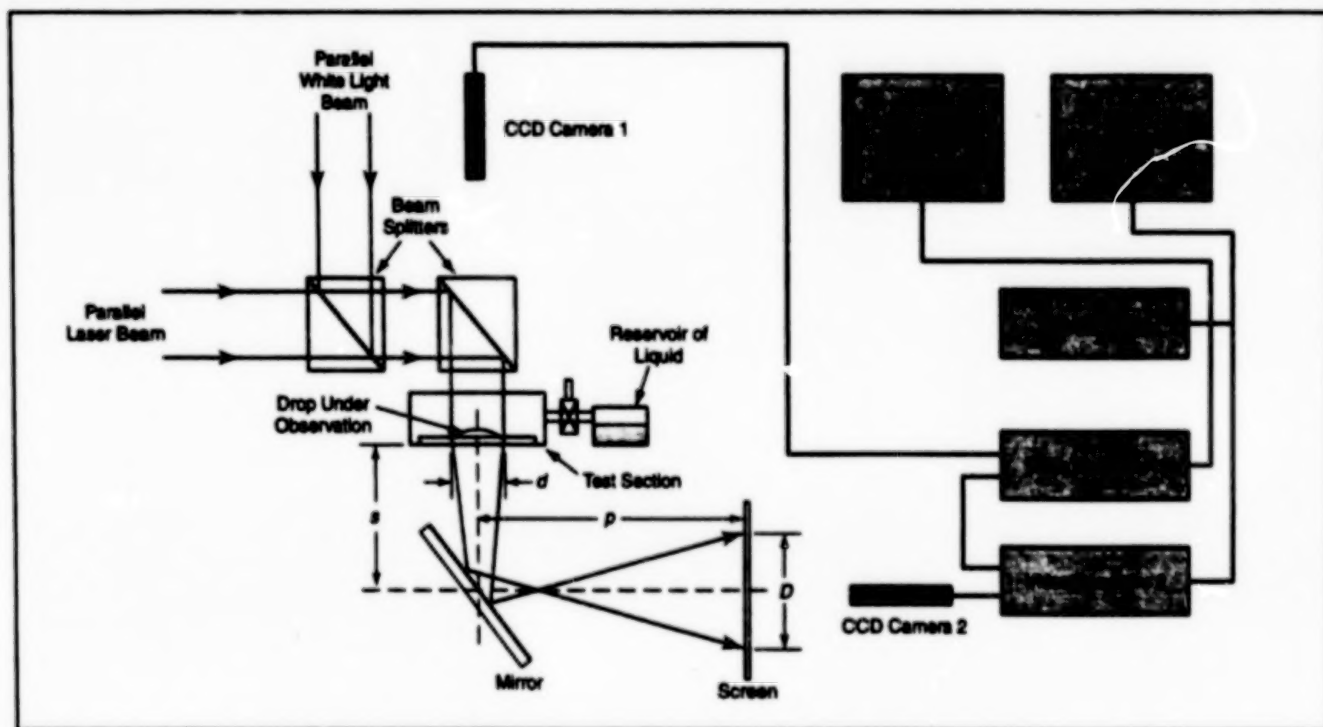


Figure 1. The Time-Dependent Diameters d and D measured in images acquired by cameras 1 and 2 can be used to calculate the contact angle and rate of evaporation of the drop in the test section.

Figure 1 depicts an apparatus that simultaneously and synchronously records magnified ordinary top-view video images and laser-shadowgraph video images of a sessile drop. The real-time values of contact angle and rate of evaporation of the drop as functions of time can be calculated from the apparent diameters of the drop in the sequences of the images. In addition, the shadowgraphs contain flow patterns indicative of thermocapillary convection (if any) within the drop. These time-dependent parameters and flow patterns are important for understanding the physical processes

involved in the spreading of evaporating liquids in such diverse technological applications as coating (including painting), film cooling, processing of materials, lubrication, and boiling. Study of the spreading of drops can also contribute to understanding of the spreading of biological cells.

The apparatus includes a combination light source of a collimated white-light beam and a collimated laser beam (omitted from the figure), which are used to observe the ordinary top-view images and the shadowgraphs, respectively. Charge-coupled-device (CCD) camera 1 acquires

the ordinary top-view video images, while CCD camera 2 acquires the shadowgraphs. The drop acts as a plano-convex lens, focusing the laser beam to a shadowgraph on the projection screen in front of CCD camera 2.

The equations for calculating the contact angle and rate of evaporation of the drop are readily derived, starting from the basic equation for the focal length of a plano-convex lens with the drop size. The derivation is simplified by invoking the assumptions that (1) the mass of the drop is sufficiently small that its shape

closely approximates a section of a sphere and (2) the drop is thin enough that its focusing action can be represented adequately by the thin-lens approximation. Omitting intermediate steps of the derivation for the sake of brevity, the results are the following:

The time-dependent radius of curvature of the spherical drop surface is given by

$$R(t) = (n-1)(s+p) \frac{d(t)}{d(t)+D(t)}$$

where n is the index of refraction of the liquid in the drop, s and p are constant dimensions indicated in the figure, d is the time-dependent diameter of the drop as measured in the ordinary image acquired by CCD camera 1, and D is the time-dependent diameter of the shadowgram as measured in the image acquired by CCD camera 2 (see Figure 2).

The time-dependent contact angle is given by

$$\theta(t) = \arcsin \frac{d(t)}{2R(t)}$$

The rate of change of volume of the drop (the negative of the rate of evaporation) is given by

$$\dot{V} = 2\pi h \dot{h} \left(R - \frac{h}{3} \right) + \pi h^2 \left(\dot{R} - \frac{\dot{h}}{3} \right)$$

where

$$h = R - \sqrt{R^2 - d^2/4}$$

and the overdot signifies differentiation with respect to time.

This work was done by David F. Cheo of Glenn Research Center and Nengli Zhang of Ohio Aerospace Institute. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be

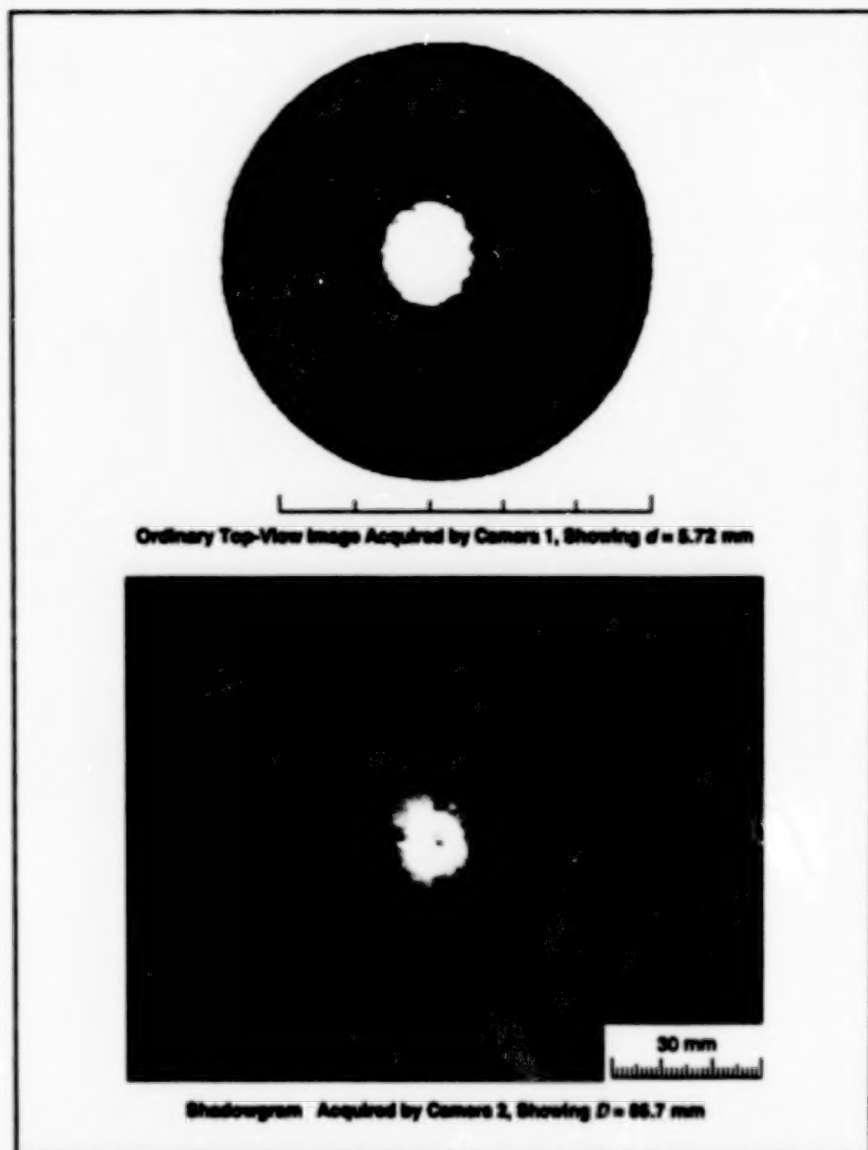


Figure 2. These images were acquired simultaneously, by use of the apparatus of Figure 1, during observation of an evaporating sessile drop of trichlorotrifluoroethane.

addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000

Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17075.

Field-Reversed Magnetic Mirrors for Confinement of Plasmas

The mirror magnetic-flux density needed for confinement would be reduced.

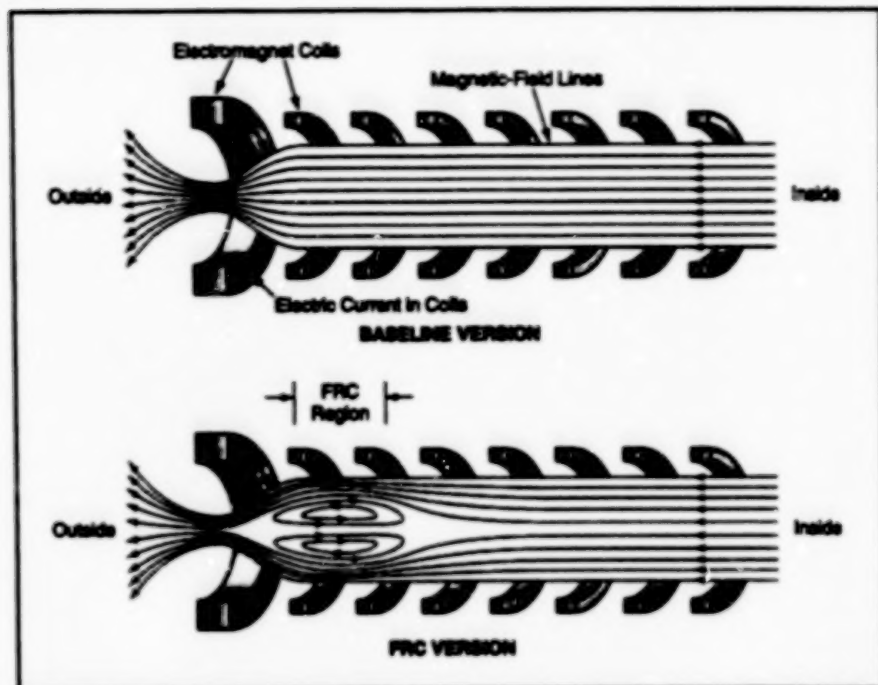
Marshall Space Flight Center,
Alabama

A field-reversed configuration (FRC) has been proposed for a magnetic mirror—a solenoidal electromagnet configured and operated in such a way as to effect at least partial confinement of a plasma. Magnetic mirrors had been investigated for potential use as plasma-confinement devices in nuclear fusion reactors, and had been largely rejected for that use because, as explained below, they allow too much plasma to escape. The proposed FRC is

intended to increase the degree of confinement achievable by a mirror magnetic field of a given flux density and/or to reduce the flux density needed to obtain a given degree of confinement. (Whether the increase in effectiveness of confinement would be sufficient to justify the use of magnetic mirrors in fusion reactors remains to be seen.)

The figure depicts baseline and FRC versions of a typical magnetic mirror at one

end of a fusion reactor. In the baseline version, the magnetic mirror is only partially effective in that a substantial amount of plasma escapes along the magnetic field lines at the outer end. Efforts to reduce the rate of loss of plasma by increasing the mirror magnetic field have been unsuccessful because the required mirror magnetic-flux density is unrealistically high. Other measures intended to reduce the width of the throat through which the plas-



A Toroidal Plasma-Magnetic-Field Plug would be formed in the FRC version and would resist the loss of plasma through the magnetic mirror.

ma escapes have been only partially successful; these measures include the use of multiple mirrors and of various types of thermal barriers.

In the terminology of plasma science as applied to a magnetic mirror like the one shown in the figure, "field-reversed configura-

tion" ("FRC") refers to a family of compact toroidal magnetic-field/plasma formations in which an azimuthal electron current flows and gives rise to a poloidal magnetic-field component that can be strong enough to reverse the polarity of the magnetic induction along the cylindrical axis. FRCs have

been investigated previously, but not for the use proposed here.

According to the proposal, the FRC would reduce the loss of plasma by at least partly plugging the throat of the magnetic mirror. The requirement for design and operation of the magnetic-mirror magnets would be reduced to one of constricting the throat (as defined by the magnetic-field lines) just enough to prevent expulsion of the FRC plug; it should be considerably easier to satisfy this requirement than to attempt to reduce the loss of plasma by applying a magnetic field strong enough to constrict the throat severely.

Further research will be necessary to identify the best technique for effecting the FRC. One notable technique, pioneered at the University of Washington, involves the superposition of a magnetic field that rotates at a frequency between the electron and ion gyrofrequencies. Under some circumstances, such a magnetic field can give rise to a stable, persistent FRC.

This work was done by William J. Enrich, Jr., of Marshall Space Flight Center.

This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at (256) 544-5226 or sammy.nabors@msfc.nasa.gov. Refer to MFS-37389.

Updated Multidisciplinary Optical-System-Analysis Software

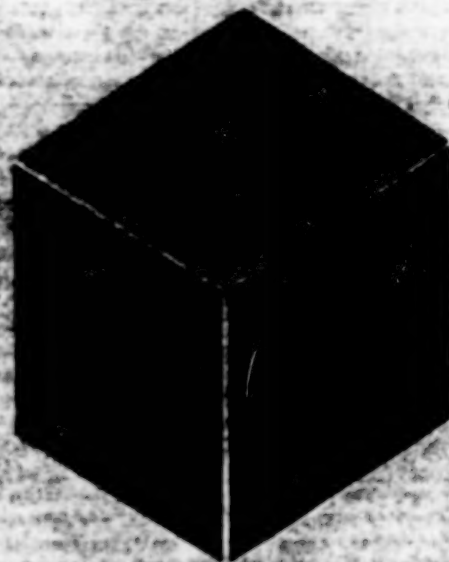
Version 5.0 of the Integrated Modeling of Optical Systems (IMOS) software has been released. A previous version was described in "Software for Multidisciplinary Analysis of Optical Systems" (NPO-20536), NASA Tech Briefs, Vol. 24, No. 11 (November 2000), page 36. In both versions, IMOS is a MATLAB™ computer program that provides many functions for analysis of a system represented by mathematical models of its thermal, structural, control, and/or optical aspects. IMOS is unique in making it possible to perform the entire multidisciplinary analysis in one program. The new features incorporated into version 5.0 include a capability for calculating stresses in rods and beams, a utility

subprogram that generates equivalent properties of laminates, a three-dimensional-viewing subprogram, a provision for temperature-dependent heat input for thermal analyses, a provision for a simulated stiffness for the drilling degree of freedom of a plate structural element, a provision for a lumped-mass formulation for a beam, a capability to orient properties of materials with respect to plate structural elements, plate-to-acoustic and beam-to-acoustic connections for statistical energy analysis, geometric stiffnesses for plate elements (for buckling analysis), subprograms for translation from the SINDA program to IMOS and from IMOS to the NASTRAN program, and greatly improved

subprograms for translation from IMOS to SINDA and from NASTRAN to IMOS.

This program was written by Laura Needels, Hugh C. Briggs, Daniel Ebbel, Robert Glaser, Andrew Kissel, Marie Levine, James Mealy, Mark Milman, Robert Norton, Miltiadis Papalexandris, Terry Scharton, Samuel Sirin, Tricia Sur, Wen Tse, and Walter Tsuha of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20849.



Materials

Hardware, Techniques, and Processes

- 25 Chemical Reactors Based on Catalyzed Wires
- 25 Chemical Reactors Based on Catalyzed Microtubes
- 26 Metal-Supported Catalyst Beds for Reacting CO_2 With CH_4

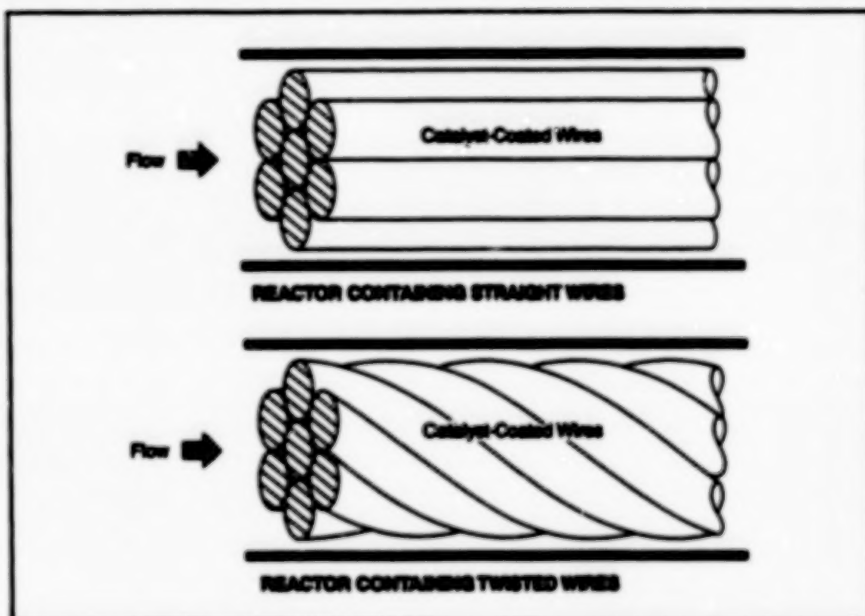
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Chemical Reactors Based on Catalyzed Wires

These reactors could offer advantages over traditional packed catalyst beds.

NASA's Jet Propulsion Laboratory,
Pasadena, California



Catalyst-Coated Wires would be placed in tubular reactors, where they would make contact with flowing reactants. The wires could be straight or twisted, depending on the required characteristics of the flow. Other aspects of the wire and tube geometries and the nature of the catalytic coating(s) could also be chosen to suit the application.

In catalytic flow-through chemical reactors being explored for space vehicle applications, the catalysts would be supported on the surfaces of wires, instead of on particles, as are typically used in traditional packed beds. The original intent of the proposal was to make it possible to build controllable, efficient catalytic hydrazine-decomposition microthrusters for small spacecraft. The basic concept of the proposal should also prove applicable to other flow-through catalytic reactors; for example, reactors that could be used in removing trace contaminants from the environment.

Traditional packed catalytic beds have several disadvantageous characteristics that make control difficult and that pose

obstacles to scaling down to the micro-thruster size range. These characteristics include high back pressures through the beds, attrition due to flaking and spalling of catalyst particles, and difficulty of fabrication in small sizes. Usually, as a result, it becomes necessary to make the beds larger than desired, with the further result that propellant is wasted and thermal masses are large (and therefore response times are undesirably long).

The basic concept of the catalyzed-wire reactor allows for adaptation to numerous variations. A reactor of the proposed type could be as simple as a straight tube containing a single catalyst-coated wire suspended on the cylindrical ends. The wire and catalyst could be made of any of a

variety of materials; for example, in one application, there might be a need for a tungsten wire with a washcoat (e.g., alumina) supporting a catalyst like platinum. In most cases, multiple catalyst-coated wires would likely be needed. Different wire material could be coated with different catalysts that would be optimized for different reaction temperatures. Catalyst preparation procedures (i.e., washcoat, catalyst, inclusion, etc.) would follow the protocols typically described for metal-supported catalysts. Wires could be made straight or twisted (see figure), wires could be all of the same diameter or of different diameters, and wires could be spaced apart at various distances; the foregoing choices could be made in conjunction with the choice of the shape and inside dimensions of the reactor, all in an effort to optimize the flow or to accommodate a wide range of flow variables in the reactor.

This work was done by Gerald Voeks, J. Morgan Parker, Amy Hart, and Juergen Mueller of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Technology Reporting Office
JPL

Mail Stop 122-116
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

Refer to NPO-20507, volume and number of this NASA Tech Briefs issue, and the page number.

Chemical Reactors Based on Catalyzed Microtubes

Microtubes would help to damp pressure excursions that disturb desired flows.

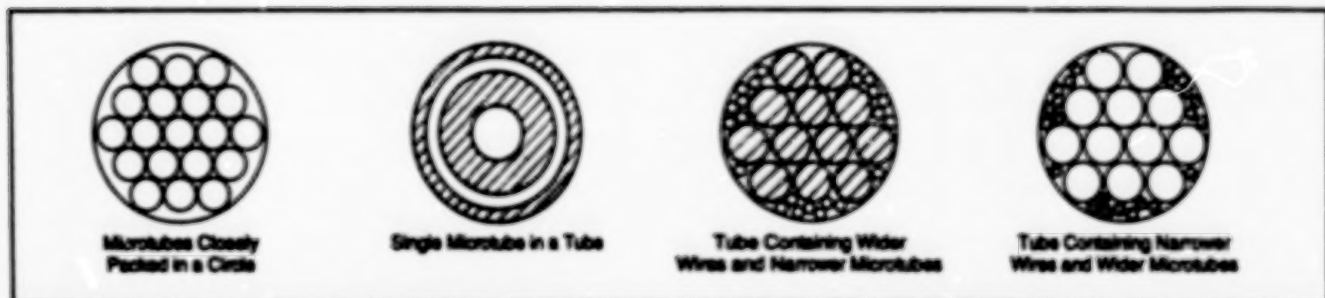
In an extension of the concept reported in the preceding article, catalytic flow-through chemical reactors of a proposed type would contain catalyst-coated microtubes, possibly in combination with catalyst-coated wires. In addition to the advantages afforded by the catalyst-coated

wires described in the preceding article, the microtubes would offer a capability to damp sudden increases in pressure.

In the original rocket-thruster application, such a pressure excursion can occur upon ignition of a propellant fluid in a catalytic reactor; the pressure excursion can

cause blow-back and/or pooling of propellant fluid in the propellant-supply system and/or in the reactor; this causes a departure from the desired mode of operation. Therefore, it is desirable to damp the pressure excursion.

In designing such a reactor according



Catalyst-Coated Microtubes would be placed in tubular reactors, possibly along with wires. The sizes, shapes, and materials of the reactor components would be chosen to obtain the desired combination of fluid-dynamic, thermal, and chemical characteristics.

to the proposal, one would provide that the microvoids in the microtubes contain sufficient volume to accommodate the rapid expansion that occurs upon ignition of the propellant. The basic concept of catalyzed-microtube reactors admits of numerous variations, including variations like those described in the preceding article for catalyzed-wire reactors. In addition, a reactor could

contain one or more microtube(s), possibly with one or more wire(s). Diameters of tubes and/or wires could be varied to allow cross flow in addition to the main flow along the reactor. Some wires and/or tubes could be catalyzed and some uncatalyzed. Some could be thermally conductive, some thermally insulating. These and other variations could be effected in an effort

to optimize the fluid-dynamic, thermal, and chemical aspects of operation over the anticipated range of flow variables.

This work was done by Gerald Voecks, J. Morgan Parker, John Blandino, and David Barne of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20508

Metal-Supported Catalyst Beds for Reacting CO₂ With CH₄

The beds are heated internally, by passing electrical currents through the supports.

NASA's Jet Propulsion Laboratory,
Pasadena, California



(A) Disassembled Corrugated Catalyst Bed



(B) Assembled Corrugated Catalyst Bed

This Prototype Catalyst Bed contains overlapping pairs of smooth and corrugated metal strips. The strips are covered by a washcoat of alumina, in which particles of platinum and rhodium (the catalysts) are dispersed.

Metal-supported catalyst beds with improved thermal and flow characteristics for promoting endothermic chemical reactions are undergoing development. In the proposed original application, catalyst beds of this type would be used on Mars to produce hydrogen from an endothermic reaction between carbon dioxide and methane. The empirical equation for this reaction is:

$$\text{CO}_2 + \text{CH}_4 \rightarrow 2\text{CO} + 2\text{H}_2$$

(The subsequent reaction of carbon monoxide with water will generate additional hydrogen as shown in $\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$.) Hydrogen is then available as a propellant for launching payloads from the Martian surface or as a fuel for fuel cells generating power for surface mobility or stationary electricity.

The basic principles of operation of these catalyst beds are also applicable to steam reformers and other catalytic reactors used on Earth to produce fuels and some specialty chemicals. With respect to endothermic reactions that one seeks to catalyze, the developmental catalyst beds offer advantages over traditional packed catalyst beds, as explained below.

In a typical traditional case, the heat needed for an endothermic reaction is generated outside a reactor and transferred through the reactor wall to a bed of packed catalyst particles inside the reactor. The energy efficiency of the reactor is diminished because (1) the thermal resistance of the wall and (2) the parasitic loss of heat from the external heater to the environment.

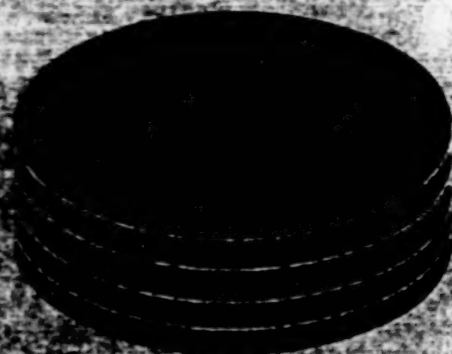
A catalyst bed of the type now undergoing development consists of a metal support coated with a material that consists of, or contains, one or more catalysts. The center mandrel and the outside wall of the metal support are connected to a source of dc electric power. In operation, the metal support is heated by passing an

electric current through it. Efficiency is increased because the losses associated with the thermal resistance of the reactor wall and parasitic transfer of heat from an external heater to the environment are eliminated. In addition, because heat is supplied to the catalyst more directly, it is possible to exert better control over the endothermic reaction.

The metal support is corrugated (see figure) to make the reactants flow turbulently; this feature enhances (relative to the packed-bed case) both the mixing of the reactants and the transfer of heat from the support to the reactant mixture. As a result of the combination of internal electrical heating and turbulence, the overall conver-

sion efficiency for a reactor of a given size is increased or, equivalently, the size of the reactor needed to achieve a given conversion efficiency is reduced. Moreover, the degree of utilization of catalyst applied to the surface of the internally heated support is greater than the degree of utilization of catalyst in or on conventional catalyst rings, cylinders, and pellets, so that less of the catalyst is needed to drive a reaction with a given conversion efficiency.

This work was done by Gerald Voecks of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20484



Computer Programs

Electronic Systems

- 31 Software for Analyzing Telecommunication Link Performance

Mathematics and Information Sciences

- 31 Web-Based for Distributed Planning
- 31 Software for Parallel Adaptive Refinement of Meshes
- 31 Software for Detecting Tones in Beacon Monitoring
- 32 Automated Real-Time Spacecraft Navigation System
- 32 Software for Preprocessing of Raw SAR Data
- 32 Software for Locating Heterogeneous Data in Different Places

Computer Programs

Electronic Systems

Software for Analyzing Telecommunication Link Performance

The Telecom Forecaster Predictor (TFP) is a multi-mission computer program for analyzing deep space telecommunication links. Analysts use the TFP for link planning, performance prediction, and post-pass trending analysis. For each mission, multiple users access a controlled set of TFP software and models, but can customize their own TFP sessions. Built upon the popular MATLAB software platform, the TFP provides an environment for high-performance numerical analysis and display of results. Link configurations are specified through a user-friendly Graphical User Interface (GUI), and navigation inputs are provided through standard JPL NAIF SPICE ephemeris and attitude files, which the TFP can read directly. The TFP's building blocks are models which are created and examined using the TFP's model editing tool. Multi-mission models shared by all TFP users are provided in a carefully managed common library to avoid errors and duplication of effort. Sharing models and modeling architecture greatly accelerates the development of adaptations to support new missions. Software flow is visually traceable using the TFP's model tree. After execution, results are viewable in plot or tabular form using TFP's data visualization tools. Snapshots of link performance at a given time are provided in link budget tables.

This program was written by Kevin Tong and Ramona Tung of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20875.

Mathematics and Information Sciences

Web-Based for Distributed Planning

The RecDel System is a low-cost software application that helps different

groups of a complex project negotiate interfaces between interdependent schedules. The RecDel system is based on a concept of distributed planning, wherein the cognizant persons retain control over, and responsibility for, their own work; this contrasts with traditional centralized planning, in which responsibility and control are effectively transferred to central planners. RecDels are products, which flow between different areas of a project. The RecDel System makes it possible to identify product-specification and delivery-schedule disputes easily, solve problems quickly, eliminate schedule confusion, and verify receipt of deliveries. The RecDel System also supports action-item tracking as well as a limited earned-value capability. The outputs of the RecDel System include metric charts, Gantt charts, and a variety of text reports. Schedule reports can be generated at any time on any computer by any user for any level of the work breakdown structure. The RecDel System aids projects to effectively meet the demand for Faster, Better, Cheaper.

This program was written by Jacqueline Dunn, Steve Friedman, Glen Gira, Mark Girner, Cate Heneghan, Michael W. Hughes, Richard G. Markley, Jancis Martin, Susan McGeehan, and Karen Morrisett of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20915.

Software for Parallel Adaptive Refinement of Meshes

A software library has been developed for adaptive refinement of unstructured (that is, irregular) tetrahedral or triangular meshes that define two- or three-dimensional coordinates or volume elements used in parallel (that is, multiprocessor) finite-element or finite-volume computations. This library contains a suite of well-designed and efficiently implemented software modules that perform the operations of typical parallel adaptive-mesh-refinement (AMR) processes. An especially notable one of these operations is mesh quality control, typically guided by a local-error estimator, during successive parallel adaptive refinements. Another is balancing of computational loads among parallel processors. The library is robust and is scalable to different

numbers of processors. The software in this library was developed in Fortran 90, plus a message-passing interface (MPI) sublibrary. The design of this library supports code efficiency, modularity, and portability. At present, the library is in use on a Cray T3E and SGI Origin computers and on a Beowulf-class cluster of personal computers.

This program was written by John Z. Lou and Charles Norton of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20948.

Software for Detecting Tones in Beacon Monitoring

A software package for use in a ground receiving station detects a beacon-monitor tone transmitted by a spacecraft. To recapitulate from previous NASA Tech Briefs articles on beacon monitoring: An onboard computer processes data from onboard sensors to summarize the condition of the spacecraft in terms of one of four standard statuses, then a message is transmitted on a radio-frequency carrier as phase modulation at one of four subcarrier frequencies that correspond to the four statuses. The present software implements a weak-signal-detection algorithm. The received signal is heterodyned at nine frequencies and recorded into nine corresponding frequency bands. Nominally, there is a center carrier and four pairs of symmetrical status bands. After recording, each frequency band is subdivided into subbands with a fixed temporal duration. Within each frequency subband, there is a bank of time-sequenced subband processors. The optimal linear path in the corresponding time-frequency band space is obtained by maximizing the summed squared signal amplitudes. The maximum summed subband-processor output is selected and compared to a predetermined threshold to determine whether the corresponding status message should be deemed to have been transmitted. The frequency drift of the status tone signal must be small enough to allow the search algorithm to detect the signal over a time long enough to provide a low signal-detection threshold.

Contributors to the development of this software package were Sue Finley, Gabor Lanyi, Robert Shenwood, Miles K. Sue,

John Szijarto, and E. J. Wyatt of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21023.

Automated Real-Time Spacecraft Navigation System

The Automated Real-Time Spacecraft Navigation (ARTSN) system is a prototype of a class of software systems for automated navigation and monitoring of spacecraft from stations on the Earth. The system processes radio metric tracking data (principally, range and Doppler measurements) in real time to generate updated spacecraft navigation solutions (including projections of trajectories into the past and future), and associated coverances. The ARTSN system enables the navigation operations analyst to identify and respond to anomalies in nearly real time, when such action is most effective. In this system, validation of data and estimation of parameters for real-time trajectory and target updates are data-driven; these functions are triggered by receipt of radio metric tracking data. The system provides "one step" access to important information; the traditionally separate software components that effect the functions of generating trajectories, computing observable parameters, filtering, and mapping are integrated into the one "engine," which can be queried in real time (or off line) by a shell command (or function call) to provide state, partial-derivative, or covariance information.

This work was done by Laureano Cangahuala, Theodore Drain, Paul Burkhardt, and Vincent Palmeier of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20426.

Software for Preprocessing of Raw SAR Data

The SAR Processing System Raw Data Processor (SPS RDS) computer program is used in the Alaska SAR Facility (ASF) to scan and decode raw data that have been downlinked from the European Remote Sensing Satellite (ERS), the Japanese Earth Resources Satellite (JERS), and the RADARSAT (a Canadian Earth-observation satellite) and recorded on high-density digital tape or disk. ["SAR" means "synthetic-aperture radar."] In its scanning role, the program reads a recorded downlink bit stream, performs PRIN decoding as needed, extracts auxiliary information to identify data-acquisition times, correlates this information with spacecraft state vector information to determine locations, and maps the locations to predefined fixed frames along an orbit track. These frames are stored in an archive as they become available, and are subsequently interrogated when requests for generation of image products are received. In its decoding role, this program converts a downlink bit stream that pertains to a requested frame into files that contain decoded engineering and SAR signal data that are compatible with the computers and programs used in further processing of SAR data into final image and image data products.

This program was written by Eugene Chu and Tuan Truong of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20711.

Software for Locating Heterogeneous Data in Different Places

The Object Oriented Data Technology group at NASA's Jet Propulsion Laboratory is developing software for locating data — especially scientific data — stored in various formats on heterogeneous computer systems at different locations. The software is intended to exploit and extend advances in Internet software and in distributed object-oriented software to overcome the technological obstacles to integration of heterogeneous computing environments. The approach taken in this development involves refocusing effort on the development of metadata, which would be used to describe the available data resources and to support interoperability of computing systems. The software would manage a hierarchical conglomerate of data-set-resource definitions that would make it possible for application programs to locate the data that they require, without advance knowledge of which computer data systems and catalogs to search. This software would utilize the Extensible Markup Language (XML) and the Common Object Request Broker Architecture (CORBA) to support for interchange of data among heterogeneous sources. CORBA would enable over-the-wire exchange of XML-based profiles that would contain descriptions of data stored in remote computer systems.

This program was written by Daniel Crichton, John Hughes, Sean Kelly, and Jason Hyon of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1]. NPO-21045



Mechanics

Hardware, Techniques, and Processes

35 Thrust-Control System for Emergency Control of an Airplane

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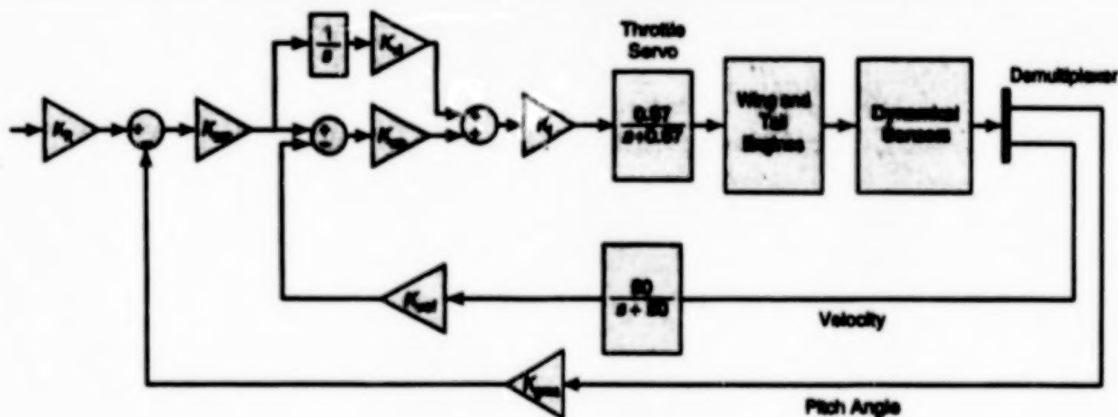
Thrust-Control System for Emergency Control of an Airplane

Suppression of the phugoid mode simplifies the pilot's task.

Dryden Flight Research Center,
Edwards, California



**MID-11 AIRPLANE LANDING UNDER THRUST CONTROL ONLY
(CONTROL SURFACES NOT MOVING)**



AUTO-THROTTLE SERVOCONTROL SYSTEM

Figure 1. This Auto-Throttle Servocontrol System responds to velocity and pitch-angle feedback by modulating engine thrust to damp the phugoid oscillation and maintain a commanded pitch angle, making it possible to land the MD-11 airplane by use of thrust control only.

Extensive redundancy is designed into aircraft flight-control systems to ensure a low probability of failure. During recent years, however, major failures of flight-control systems have occurred in several airplanes, leaving engine thrust as the flight-control mode of last resort. In some of these emergency situations, engine thrust was successfully modulated by the pilots to maintain flightpath or pitch angle, but in other situations, lateral control was also needed. In the majority of such cases, crashes resulted, and over 1,200 people died because of control-system failures.

Thus, the challenge has been to create sufficient thrust-modulation control to safely fly and land an airplane. A thrust-modulation control system designed for this purpose was flight-tested in a propulsion-controlled aircraft (PCA) — an MD-11 airplane. The results of the flight test showed that without any operational control surfaces, one can land a "crippled airplane" (U.S. Patent 5,330,131). This flight program also verified that the "weak link" is the phugoid mode, which is also known as the long-period pitch mode. The low phugoid damping and a high pilot workload made manual landings exceedingly

difficult near the ground. However, a PCA system makes landings feasible. The installation of the original PCA system entailed modifications not only of the flight-control computer (FCC) of the airplane but also of each engine-control computer. Inasmuch as engine-manufacturer warranties do not apply to modified engines, the challenge was to create a PCA system that does not entail modifications of the engine computers.

The response to the challenge was a method of providing longitudinal (pitch) control through modification of only the program of the FCC, without any changes

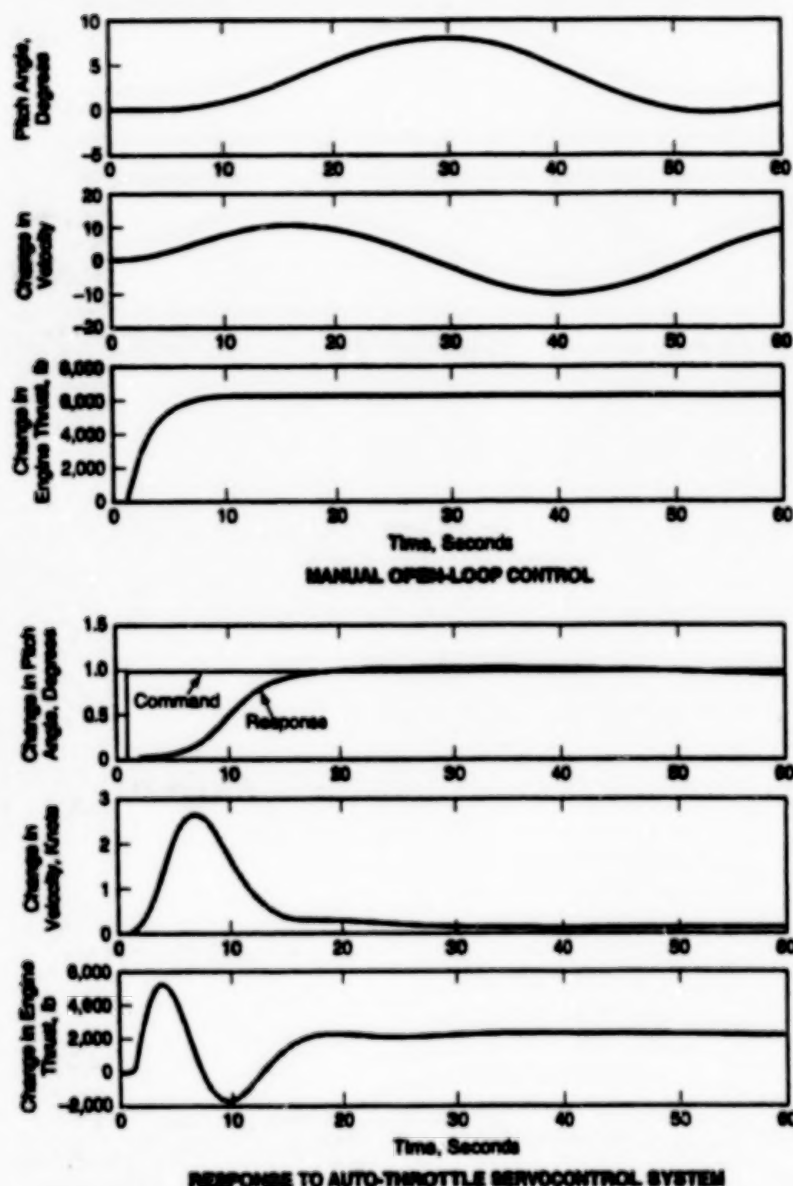


Figure 2. The Phugoid Oscillation is excited when the engine thrust is increased in manual open-loop control. The plots in the upper part of this figure represent the dynamics of an MD-11 airplane in which the thrust of each of the wing engines has been increased by 6,000 lb (≈ 27 kN). On the other hand, the phugoid oscillation is suppressed when the system of Figure 1 is used to control the wing and tail engines.

in the engine-control computers and without changes in cockpit hardware. In the event of a failure in the primary flight-control system, the engines can be used to dampen the phugoid mode, and in the

case of a multiple-engine airplane, they can be used to land the airplane safely. This method relieves the pilot of the longitudinal-control task, enabling the pilot to concentrate on using differential thrust to

keep the wings level for landing. This may seem difficult at first, but lateral control is made simpler when the phugoid motion is highly damped by the closed-loop system shown in Figure 1.

This control system, denoted the auto-throttle servocontrol system, strives to maintain a commanded pitch angle in the face of velocity and pitch-angle feedback. The pilot commands this system by use of a thumb wheel. The output of this system drives an auto-throttle servo forward or back, thereby causing the engines to increase or decrease thrust, and thereby, in turn, controlling the pitch of the airplane in such a way as to keep the phugoid mode well damped. In the many multiple-engine airplanes in which auto-throttle systems are already in place, no hardware changes are needed.

Suppose that one were flying a wide-body airplane in which control surfaces had been rendered inoperable by a full hydraulic failure and the airplane was not equipped with the present auto-throttle servocontrol system. In order to increase the pitch angle, one would slowly increase the thrust, as shown in the upper part of Figure 2. As the thrust was increased, the phugoid mode would be excited, causing the pitch and velocity to oscillate. On the other hand, if the airplane were equipped with the present auto-throttle control system, then the airplane would behave as shown in the lower part of Figure 2. The pitch angle in the case illustrated would increase by 1° , tracking the command very well. The phugoid mode would be well damped. The thrust would be increased and decreased automatically, as needed to control the motion of the airplane.

This work was done by John J. Burken and Bill Burcham of Dryden Flight Research Center. Further information is contained in a TSP [see page 1].

This invention has been patented by NASA (U.S. Patent No. 6,041,273). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to Technology Commercialization Office, Dryden Flight Research Center; (661) 276-3720. Refer to DRC-96-07.



Fabrication Technology

Hardware, Techniques, and Processes

39 Weld Repair of a Directionally Solidified Superalloy Article

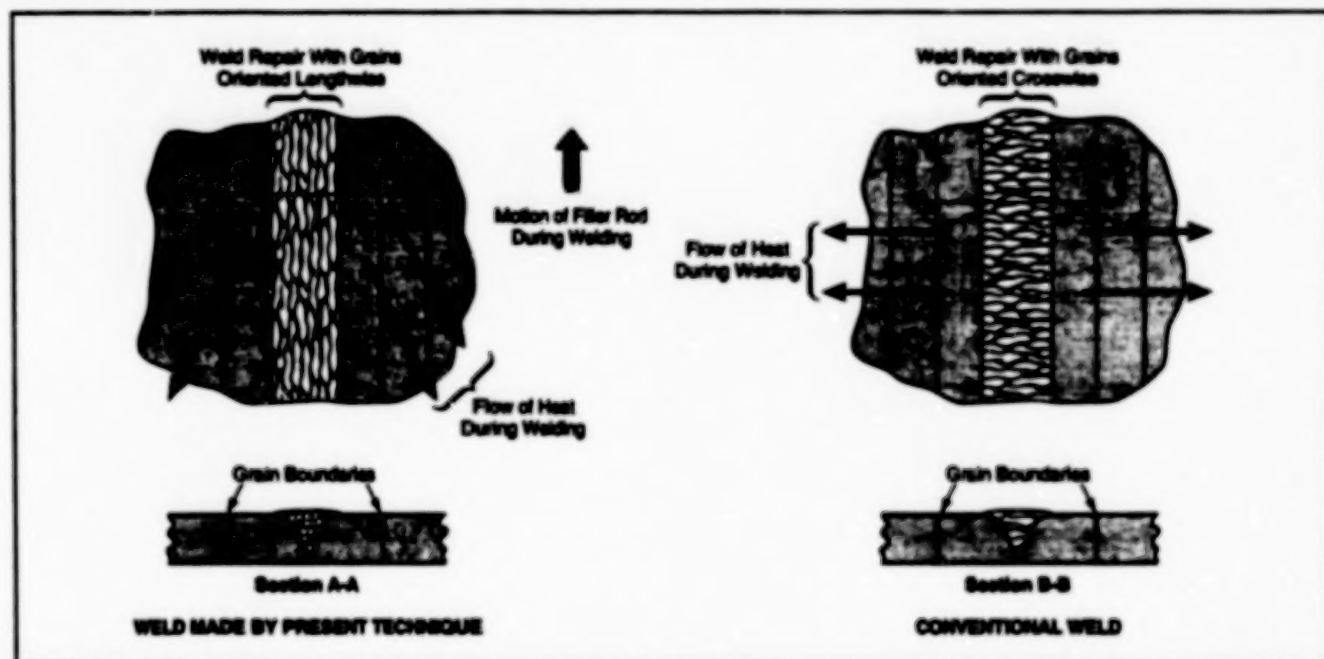
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Weld Repair of a Directionally Solidified Superalloy Article

The weld is also directionally solidified to preserve the desired grain structure.

John H. Glenn Research Center,
Cleveland, Ohio



The grains in a weld by the present technique are oriented predominantly along the direction of the original grain structure of the surrounding material, whereas the grains in a conventional GTA weld are oriented perpendicularly.

An arc-welding technique for repair of a directionally solidified (DS) nickel-base superalloy article (e.g., a turbine blade or vane) has been devised. The technique equally is applicable to a part as cast or a part that has been damaged in use. Unlike ordinary gas tungsten arc (GTA) welding, this technique results in a predominately DS microstructure in the repaired region, similar to the microstructure of the DS casting. In addition, whereas ordinary GTA welding often involves the use of a filler material different from that of the work-piece, the weld filler material used in the present technique is of the same composition as that of the DS casting, so that undesired localized chemical differences are not introduced into the repair region.

In this technique, the weld-repair area is shielded from atmospheric contamination;

typically, shielding is accomplished by placing the article in a chamber that contains a protective argon atmosphere. To minimize residual stress and distortion, the article is maintained at a high temperature (approaching the liquidus of the DS material) while the weld is being made. After the welding arc is struck, the weld filler rod is moved along the repair region parallel to the direction of the original grain structure of the article. The filler material solidifies by epitaxial nucleation and growth of grains as typically observed on most weld repairs.

The unique feature of this technique is the combination of the directional deposition of the filler material and the high process temperature. This feature promotes directional grain growth parallel to the original DS grain structure. As shown

in the figure, this is much different from the microstructure of a conventional GTA weld, in which there are typically two rows of converging, columnar grains, the major axes of which are perpendicular to the direction of the original DS structure.

This work was done by Russell Wayne Smahey, John Herbert Snyder, and Bruce Leonard Bome of General Electric Co. for Glenn Research Center. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 22000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16865.

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Mathematics and Information Sciences

Hardware, Techniques, and Processes

- 43 Partial Subtractive Dither for Lossy Data Compression
- 43 Wavelet Analysis To Predict Limit Cycles

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Partial Subtractive Dither for Lossy Data Compression

A new technique provides a compromise between benefits and costs of standard subtractive dither.

NASA's Jet Propulsion Laboratory,
Pasadena, California

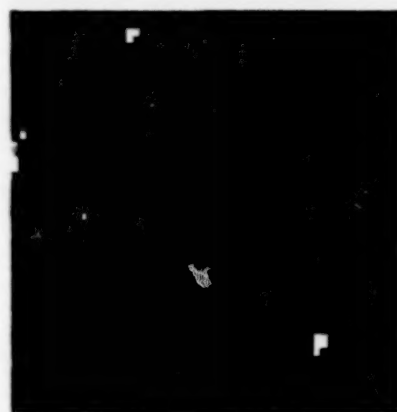
A technique of partial subtractive dither has been developed to improve the performance of any of a variety of near-lossless data-compression algorithms. The technique may be applicable to compression of scientific and medical image data.

To those skilled in the art of data compression, the use of subtractive dither to reduce the undesired quantization artifacts produced by lossy data-compression algorithms is well known. These artifacts include (1) biased average signal values in some regions of a signal, (2) step-like signal-value profiles in slowly changing portions of the signal, and (3) erasure of faint features that, if they occupied a sufficiently large area, would be detectable in the original signal.

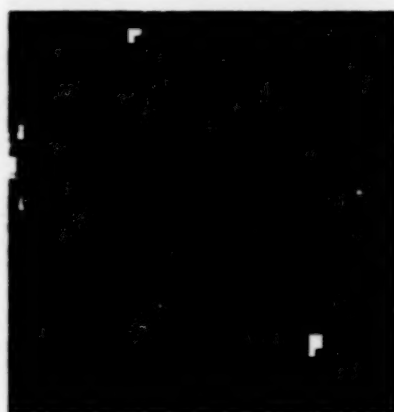
The type of subtractive dither used heretofore, called "standard subtractive dither," involves a dither distribution that is uniform over a range equal to the quantization step size of the algorithm to which it is applied. Standard subtractive dither incurs costs in the form of an increase in rate (in other words, a reduction in compression) and an increase in distortion.

In the present technique of partial subtractive dither, the dither distribution is uniform over a range smaller than the quantization step size. The choice of a uniform distribution is motivated by a desire to optimally compromise between the benefit (reduction in quantization artifacts) and the costs (increases in rate and distortion) of standard subtractive dither. Under some reasonable assumptions, the dither distribution should be chosen to be uniform, with its range chosen according to the degree of dithering desired.

The figure shows the effects of compression followed by decompression of an image. As the degree of dithering



(a) Original image



(b)



(c)



(d)

The Original Image Was Compressed with different degrees of subtractive dither, then decompressed. As dither increases, as shown in (b), (c), and (d), respectively, quantization artifacts are reduced, while graininess is increased.

increases from zero (no dither) through partial to standard, the appearance of streaks and artificial regions of constant intensity decreases, while the overall grainy appearance increases.

This work was done by Matthew Kilmes of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20964

Wavelet Analysis To Predict Limit Cycles

It is possible to predict the airspeed of onset of dangerous oscillations.

A method to predict the onset of a limit cycle for an aeroelastic testbed has been developed. The prediction is based on wavelet processing of measurement data that have been recorded under various flight conditions. The method has been considered for only a small testbed; however, the concepts may lead to techniques that could

assist in prediction of the aeroelastic behaviors of aircraft during flight testing.

Some background information is prerequisite to an explanation of this development. The term "wavelet" denotes a signal that is nonzero for a short time. The relevant wavelet in the present case is the Morlet wavelet, which is essential-

Dryden Flight Research Center,
Edwards, California

ly a windowed sinusoidal signal of finite length. The Morlet wavelet is a function of parameters, called scale and position, that affect, respectively, the period of the sinusoidal component and the time upon which the nonzero component is centered. Wavelet processing involves computation of the magnitudes of corre-

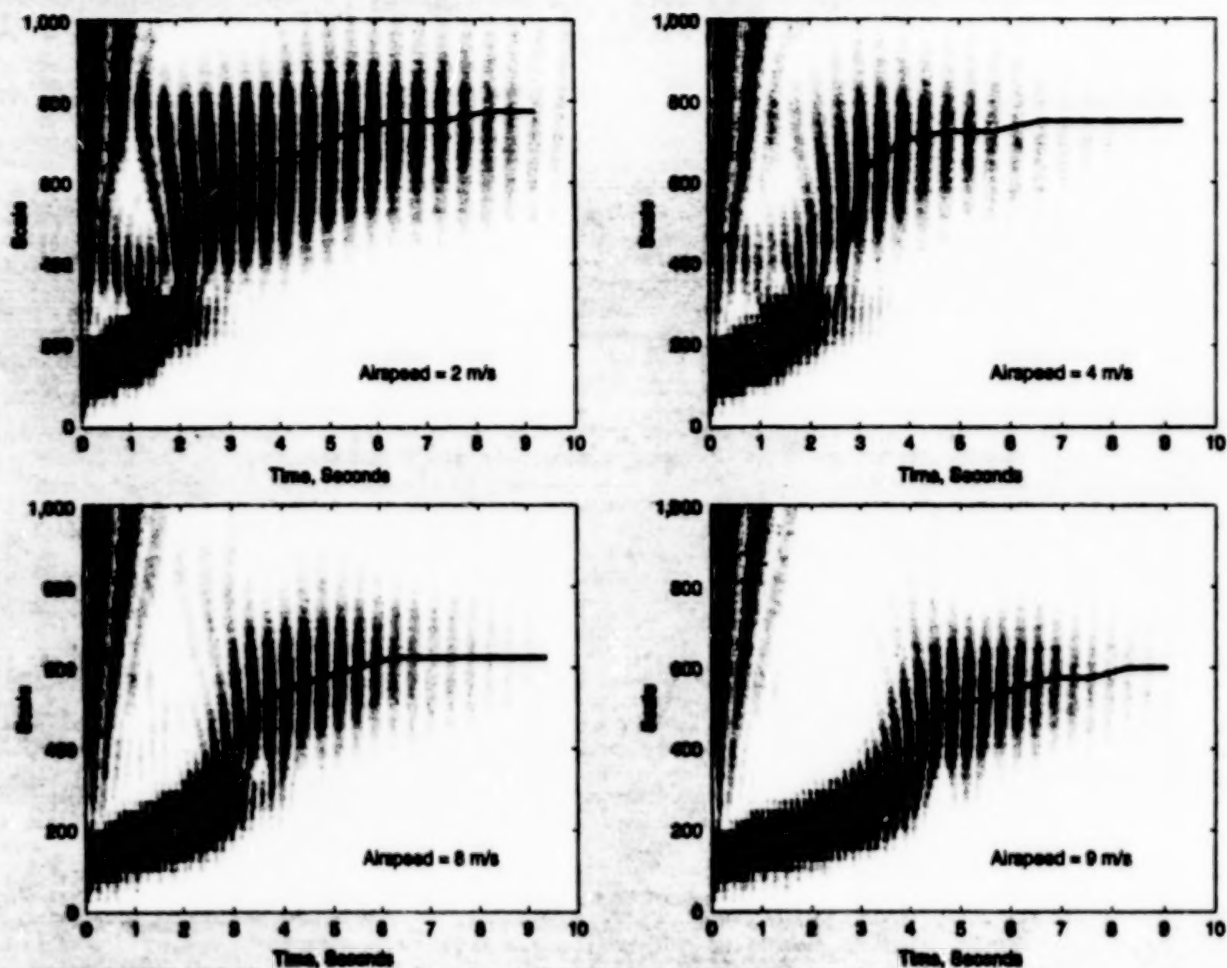


Figure 1. These Maps Were Generated by Wavelet Analysis of the pitching motion of a wing at four different airspeeds.

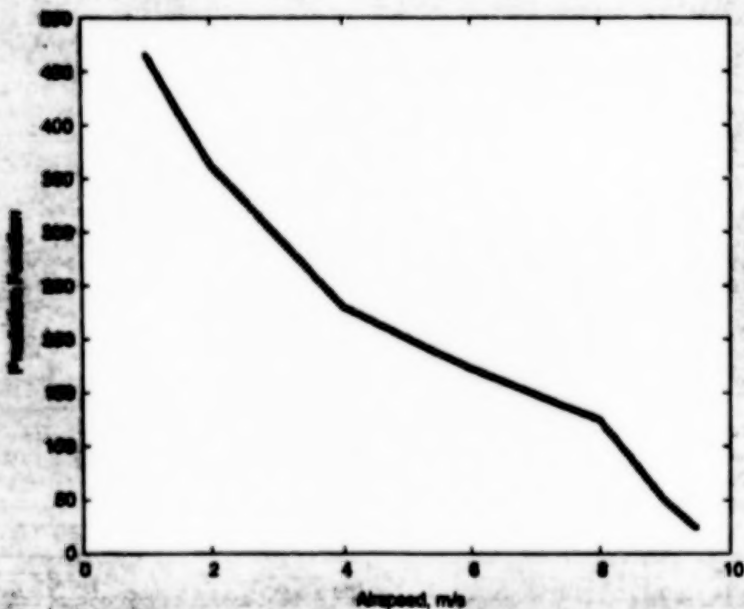


Figure 2. The Prediction Function, when linearly extrapolated, becomes zero at an airspeed close to the measured value (9.8 m/s) for the onset of the limit cycle.

lation between a measured signal and wavelets of different scales and positions. The wavelets with the highest correlation magnitudes represent dominant features in the measurement data.

Wavelet analysis is useful for extracting features in data that relate to nonlinear dynamics. These features can be used to indicate the nature of nonlinearities in an aeroelastic testbed, as reported, for example, in "Characterizing Nonlinear Dynamics by Use of Wavelet Analysis" (DRC-98-42), *NASA Tech Briefs*, Vol. 23, No. 9 (September 1999), page 70. These features are also the main mathematical tools used in the present method for predicting limit cycles.

In a typical application that involves aeroelasticity, for the purpose of the present method, limit cycles are behaviors that basically consist of steady oscillations of parts of an aircraft. These oscillations are usually stable in the sense that they are of a fixed amplitude; however, they are highly dangerous in flight because of their effect on the pilot and

the stress caused to the airframe. It is particularly difficult to predict the onset of limit cycles because they are associated with nonlinearities that are often poorly represented in analytical models.

In the present method, responses from an aeroelastic testbed are analyzed at a series of increasing airspeeds in order to develop an ability to predict the onset of a limit cycle. The testbed is a standard wing section that undergoes pitching and plunging motions. The wing is also equipped with a nonlinear spring that affects the pitching motion and provides the dynamics for the limit cycle. This limit cycle occurs at an airspeed of 9.8 m/s.

Figure 1 shows the maps that result

from wavelet processing of pitch measurements at different airspeeds. The color varies from white to black to indicate low to high magnitude of correlation between the signal and the wavelets. Of particular interest is the peak level of correlation at each point in time. This feature is indicated by the solid curved lines through the maps.

The feature associated with the peak level of correlation seems to be related to the airspeed. Notably, the responses at low airspeeds show a sudden and large change in scale of peak correlation after a time interval of 2 seconds, whereas at high airspeeds, the change is more gradual and occurs at later times.

A prediction function for the limit cycle can be computed as a ratio between (1) the magnitude of the maximum change in scale and (2) the time when this change occurs. A plot of this function (see Figure 2) clearly demonstrates a trend toward zero as the airspeed increases. A linear extrapolation of the function becomes zero near 9.8 m/s; thus, the wavelet approach appears to enable correct prediction (through extrapolation) of the onset of the limit cycle.

This work was done by Rick Lind and Martin Brenner of Dryden Flight Research Center. Further information is contained in a TSP [see page 1].
DRC-01-10

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